S
628.16
809
W3mee
1990?

Mine Effluent Effects on Non-Point Source Contaminants in the Blackfoot River, Montana

A Report to

the Lewis and Clark City-County Health Department

and the

Montana Department of Health and Environmental Sciences

Water Quality Bureau

by
Johnnie N. Moore
Missoula, Montana

STATE DOCUMENTS COLLECTION

OCT 19 1992

MONTANA STATE LIBRARY
1515 E. 6th AVE.
HELENA, MONTANA 59620

Abstract

Metal concentrations determined in benthic biota, fish livers, water, and fine-grained sediment were integrated to determine the bioavailability in Blackfoot River, Montana affected by acid mine effluent. Solute and particulate contaminants decrease rapidly downstream from headwater sources, but some extend through an extensive marsh system in the upper reaches of the river. The marshes do not completely retard downstream contamination of the food web and particulate contaminants generally penetrate to a greater extent than do solute contaminants. Metals differ in their bioavailability within and below the marsh system. Cd was most consistently accumulated in the food web, and the general order of downstream mobilization of bioavailable metals appears to be Cd, Zn>Cu>As, Ni. Because these systems fail to mitigate upstream inputs, elimination of sources of metals may be the most effective mechanism for preventing extended, long-term riverine contamination in the Blackfoot drainage. The marsh system must also be managed to maximize retention of contaminants to protect downstream riparian environments from further degradation.

PLEASE RETURN

Introduction

As water supplies are stressed, there is concern over the effects and extent of metals contamination in the headwaters of drainage basins in western North America from past hard-rock mining activities (Nova 1990). However, systematic studies of downstream sediment contamination and subsequent availability to biota of metals mobilized by acid mine drainage are rare. Many studies of metal contaminated riparian systems have focused on only a few Km of river near the input of contaminants (Moraiarity et al. 1982; Bradley and Cox 1987) and do not integrate contamination in the solid and aqueous phases with the biologic system. As well, metal bioavailability in cobble-bed rivers is poorly understood in general, partly because the biological communities of such systems are complex and difficult to sample. In this report I present data showing that headwater inputs of aqueous and particulate metal contaminants into the Blackfoot River affects chemical trends, metal concentrations and metal bioavailability over a distance of tens-of-km from the source. The goal is to understand the biological fate of metals mobilized by acid mine drainage in the Blackfoot River, and specifically address the following questions: 1) Are high concentrations of metals near input of mine effluent available to resident biota? 2) Do beaver ponds/marsh systems (near the headwaters) mitigate contaminant transfer downstream? 3) If metals are trapped in the marsh system do they remain available to resident biota? 4) How does spacial distribution of contamination in food webs compare to the particulate and aqueous phases of contamination? 5) Does contaminant bioavailability differ among metals or taxa? And, 6) Does metal bioavailability vary substantially from year-to-year?

Six taxa of benthic insect larvae, from two trophic levels, and three taxa of trout were sampled as representatives of the food web in the Blackfoot River contaminated by headwater inputs of mine effluents (acid mine drainage). Metal concentrations (Al, Cd, Cu, Fe, Pb and Zn plus the metalloid As) were determined in benthic biota, fish livers, water, and fine-grained sediment of the Blackfoot River. Metal contamination in benthic insects was compared to particulate and aqueous contamination, and contamination trends compared to distribution of fish populations in the river. To assess the areal distribution of contamination, the complete river system was examined from the headwaters to its mouth, 215 km downstream, including inputs from all mine effluent sources. Comparisons were made to earlier studies conducted in 1971-75 (Spence, 1975) to determine the temporal changes in the system.

Study Area

The Blackfoot River of western Montana is a Class I trout stream (Montana Department of Fish, Wildlife and Parks classification system) dissecting geologically complex, mineralized terrains of the the northern Rocky Mountains. The river drains 6,000 Km^2, and from its source near the Continental Divide, flows 215 Km where it joins the Clark Fork River (Fig. 1). Mining in the headwaters of the Blackfoot River began in approximately 1865 and continued until after World War II. A variety of minerals and commodities were recovered including gold, silver, lead and copper from numerous small placer and hard-rock mining operations. Although milling was not widespread in the drainage, milled tailings were discharged into the headwaters at several sites. The numerous small deposits of contaminated tailings and isolated sources of contaminated mine drainage in the upper reaches of the catchment (Fig. 1; Spence 1975) are typical of many montaine areas in western North America.

The gradient of the Blackfoot River ranges from 0.5 to 60 m/Km and is characterized by distinct changes in slope. The stair-step nature of the stream profile results from deposition of glacial deposits during the Pleistocene at the mouths of several tributaries, producing low gradient reaches separated by higher gradient sections. Tributaries in the headwaters which drain the mining areas have relatively high gradients. Downstream from the mined areas, the river valley has been partially damned by Pleistocene glacial till and outwash to form several low gradient reaches. One such reach, extending from 211.6 to 196.6 Km, has three extensive marshes (river Km are measured from the mouth upstream; location of sampling sites are indicated in Appendix 1).

Earlier studies (Spence 1975) showed that acid-mine drainage caused enrichment in sulfate, metals (including Al, Cd, Ca, Cu, Pb, Mn and Zn) in Blackfoot water downstream to approximately 190 Km. Waters flowing from tunnels and bore holes were commonly of $pH < 3$ and no fish were found in tributaries affected by this acidic drainage (Spence 1975; Dollhopf *et al.* 1988). Drainage from adits and waste piles continue to supply contaminated water to the headwaters of the drainage. Spence found that bed sediment in the upper Blackfoot River was especially enriched with Cd, Cu and Zn and that the bed was coated with Fe-Mn oxyhydroxide for several Km. This contamination is still visually and chemically evident today. In the early 1970's, marshes along the upper river appeared to impede downstream movement of the metals, evidenced by reductions in contamination below the uppermost wetland (Spence 1975). This morphology

establishes a natural mitigation process that would be expected to limit downstream dispersion of mine effluents.

The benthic community in much of the Blackfoot River is a diverse assemblage of insect larvae typical of temperate, cobble-bed rivers (Spence 1975). The trout fishery is a complex, multi-species assemblage (Spence 1975; Peters and Spoon 1988). In general, eastern brook trout (*Salvelinus fontinalis*) and cutthroat trout (*Oncorhynchus clarki lewisi*) are the dominant species from the headwaters to approximately 191.5 Km. A transition zone occurs below 190km to 168.5 km where brown trout (*Salmo trutta*) dominate the assemblage. Brown trout dominate the middle section of the river but are replaced by rainbow trout (*Oncorhynchus mykiss*) in the lower river (below 85 Km). Large, fluvial bull trout (*Salvelinaus confluentus*) also are found in the middle and lower river. The trout fishery is an important recreational resource in western Montana.

Methods

Water Chemistry

Grab samples of river water were taken at 22 sites on the main stem, 9 on tributaries and 9 from contaminated tributaries (those tributaries with known mine effluent input). One sample was filtered in the field through a 0.45 μm membrane filter that was first rinsed with river water. The filtered sample was preserved for metal analyses by acidifying with concentrated, "instra-analyzed" nitric acid. Metal analyses were performed by inductively-coupled argon plasma spectrometry (ICAPES). Detection limits are listed in Table 1. Another filtered sample was left un-acidified for anion analysis by ion chromatography (IC). A third water sample was left unfiltered and un-acidified for alkalinity measurement by titration (Gran method). All samples were transported to the laboratory on ice and refrigerated until analysis. Quality control during ICAPES analysis was maintained by using field and procedural blanks and U.S. Geological Survey water standards (Table 1). IC analyses were checked using internal standards.

Sediment Chemistry

Sediment samples were taken at 43 sites on the main stem, tributaries and contaminated tributaries. Eight sites were replicated in 1988 and 1989 to determine annual variation (which was within the error of measurement). Surficial bed sediment was collected by suction in a large syringe (a turkey baster) from small deposits of fine-grained sediment over an area of 50 to 100 m^2 and composited by sieving through a 63 μm nylon screen. The resulting slurry was stored on ice, transported to the laboratory, centrifuged and dried at 70°C. Dried sediment (0.2 g) was dissolved in a microwave digestion vessel in 5ml aqua regia and 2ml HF. After microwaving for 5 min at high power, the sample was filtered and the HF neutralized with boric acid. Then the sample was diluted 500:1 (v/w) and analyzed by ICAPES. Quality control was evaluated by using NBS sediment standards (Table 1).

Table 1

Concentrations and (standard deviations) for U. S. Geological Survey (USGS) water standards, National Bureau of Standards (NBS) sediment standard and NBS bovine liver standard. Limits of detection (LOD) listed for solution only. All values listed in parts per million (ppm) for solids and mg/l for solutions, except where in weight % which is identified by an "*". NC = non certified value; BD = below detection limit.

		Water Standards				Sediment Std.		Bovine Liver	
		USGS T103		USGS T97		NBS 1645		NBS 1577a	
Metal	LOD	Given	Obtained	Given	Obtained	Given	Obtained	Given	Obtained
			(n=6)				(n=4)		
Al	0.03	0.127 (0.038)	0.136 (0.006)	0.126 (0.042)	0.156 (0.007)	2.26 (0.04)*	2.29 (0.09)*	2 (NC)	3.02 (0.51)
As	0.03	0.0032 (0.0009)	BD	0.0113 (0.0015)	BD	66 (NC)	63 (8.4)	0.047 (0.006)	BD
Cd	0.005	0.0017 (0.0004)	0.002 (0.001)	0.0163 (0.0023)	0.016 (0.002)	10.2 (1.5)	6.7 (0.5)	0.44 (0.06)	0.37 (0.02)
Cu	0.005	0.0833 (0.0057)	0.082 (0.005)	0.0168 (0.0025)	0.015 (.003)	109 (19)	101 (2.3)	158 (7)	155 (0.98)
Fe	0.005	0.041 (0.0076)	0.039 (0.002)	0.100 (0.009)	0.105 (0.004)	11.3 (1.2)*	9.16 (0.28)*	194 (20)	187 (3.5)
Mn	0.005	0.009 (0.0021)	0.007 (0.001)	0.0305 (0.0032)	0.029 (0.001)	785 (97)	695 (15)	9.9 (0.8)	9.95 (0.11)
Pb	0.04	0.0077 (0.0021)	BD	0.015 (0.0037)	BD	714 (28)	614 (16)	0.135 (0.015)	BD
Zn	0.005	0.0265 (0.0041)	0.033 (0.002)	0.153 (0.01)	0.159 (0.006)	1720 (170)	1525 (37)	123 (8)	127 (0.6)

Sampling of Benthic Insect Larvae

Samples of benthic insect larvae were collected for metal analysis from thirteen different stations in 1987, 1988 and 1989. Four stations were sampled between 190 Km and 17 Km in 1987 and eight stations through that reach in 1988. Stations between km 211.8 and km 186.6 (including km 190) were sampled in 1989. The six taxa targeted for collection were relatively abundant, larger insect larvae from three functional groups. These included two predaceous Plecoptera (stoneflies), from the family Perlidae - *Claassenia sabulosa* and *Hesperoperla pacifica*; and four Trichoptera (caddisflies), the net-spinners *Hydropsyche sp.* and *Arctopsyche grandis* from the family Hydropsychidae; the herbivore *Brachycentrus sp.* from the family Brachycentridae and the large case-bearing scavenger *Limnophilus sp.* *Brachycentrus*, *Limnophilus* and *Hydropsyche* samples were not separated to species. Metal concentrations among species of Hydropsyche do not differ greatly in other systems (Cain et al, 1989).

The larvae were collected by kick net from riffle areas. For reference, metal concentrations from the Blackfoot taxa were compared to animals from Rock Creek, an undisturbed stream located in an adjacent drainage (Luoma et al, 1989; Axtmann et al, 1990). Taxa were separated for analysis and brachycentrids and limnophilids were removed from their cases in the field. Living animals were held for 4 to 6 hours in bags of ambient water after separation for depuration of their digestive tracts before the samples were frozen. In preparation for analyses, frozen samples were thawed, the length of individuals from the larger taxa (*Claassenia* and *Hesperoperla*) was determined, and similar sized individuals were composited to a dry weight of at least 50 mg, but not more than 1.5 g. Microscopic verification of field taxonomy was conducted where necessary on frozen samples. Each composite was digested by concentrated nitric acid reflux, the concentrated acid was evaporated, and the sample was reconstituted in 0.5N HCl. Analyses in 1987 were conducted by flame atomic absorption spectrophotometry. Analyses in 1988 and 1989 were conducted by ICAPES.

The goal of benthic insect larvae collection at each site was to obtain at least 20 individuals of each available taxon with sufficient mass of each to exceed analytical detection limits. Achieving these goals for a variety of taxa in cobble-bed rivers is made difficult by the spatial, temporal and size variability typical of the benthic community (Giesey et al. 1981; Selby et al 1985). As a result, more individuals of some taxa were collected than others at each station, the number of composites that represented an individual taxon at a site varied, and not all taxa were represented at all stations. Where more than one composite of a taxon was collected, confidence intervals were calculated to determine within-site variability. These confidence intervals never exceeded 100 percent of the mean and seldom exceeded 50 percent of the mean. Data from adjacent sites also were aggregated in some cases to eliminate psuedo-replication and to statistically test if there were differences in metal concentrations between segments of the river. Difference between segments or stations were tested by one-way ANOVA or, by t-test. Data were log-transformed for statistical comparisons.

Sampling of Fish

Fish were collected for metal analyses in 1988 and 1989. The metals of principal concern in the Blackfoot (Cd, Cu, Zn) typically concentrate strongly in the liver (Bollingberg 1979; Weiner and Giesy 1979). Thus, analyses of this organ were employed to determine the distribution of metal contamination of the Blackfoot fishery, as proven effective elsewhere (MacFarlane and Franzin 1980; Roch et al. 1982). All

comparisons of metal concentrations were restricted to similar size classes within a species (Brooks et al. 1976; Chernoff and Dooley 1979). To compare contamination in the upper Blackfoot to a reference, cutthroat trout also were collected from Marshall Creek, a small stream undisturbed by mining near the Blackfoot River, but not in the drainage (not on Fig. 1). All fish were collected by electrofishing from river reaches exceeding 1 Km long, and immediately placed on ice. The length of each individual fish was measured and the liver removed for analysis within six hours of collection. Liver samples were digested by the concentrated nitric acid reflux method described above, and analyzed by ICAPES. NBS standard 50 (bovine liver) was analyzed by the same methodology (Table 1). All statistical comparisons employed one-way ANOVA with log-transformed data.

Fish populations were estimated with the mark and recapture method, employing Chapman's modification of the Peterson formula described by Ricker (1975). Variance estimates were made with Chapman's formula (Ricker, 1975). These methods were employed to provide direct comparison with a similar approach employed in earlier fish surveys in the Blackfoot (Spence 1975). Fish were sampled by electrofishing, and similar habitat was sampled from all sections that were compared. Detailed methods and a complete discussion of the fish population survey are available in Peters and Spoon (1989).

Results

Solute Contaminants

The water in the lower main stem of the river (below 190 Km) and in uncontaminated tributaries is a Ca-Mg-HCO_3 type low in sulfate, nitrate, flouride and trace constituents with pH's from 7.4 to 8.0 (Figure 2; Appendix 2). Contaminant input from mine effluent in the headwaters into the Blackfoot River is apparent from downstream trends of solute constituents. The pH of effluent in contaminated tributaries that flow into the upper 5 km of the river (mostly above the upper marsh system, but two contaminated tributaries, Paymaster and Swamp gulches, flow directly into the upper marsh), ranges from 3 to 6.5 (Figure 2A; Appendix 2). Concentrations of sulfate are extremely high in the acidic tributaries (Figure 2B; Appendix 2), and decrease downstream away from input.

Both acidity and sulfate concentration show downstream attenuation from the headwater sources in the Blackfoot River. Acidity is neutralized rapidly and reaches background (uncontaminated tributary and downstream mainstem) values before reaching the marsh system (211.6 Km). Sulfate, however, shows less attenuation and penetrates downstream through the marshes; values above background extend to 190 Km (Aspen Grove Campground). Alkalinity of some mine effluent is near zero, but alkalinity of main stem and tributary water ranges from 50 to 100 mg $CaCO_3$ (including contaminated tributaries). Alkalinity generally increases downstream (Figure 2).

Figure 2A

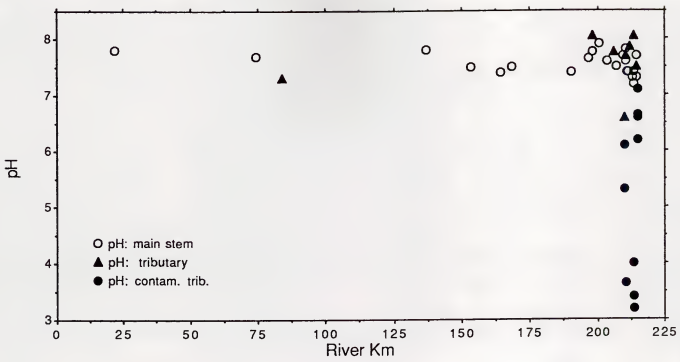


Figure 2B

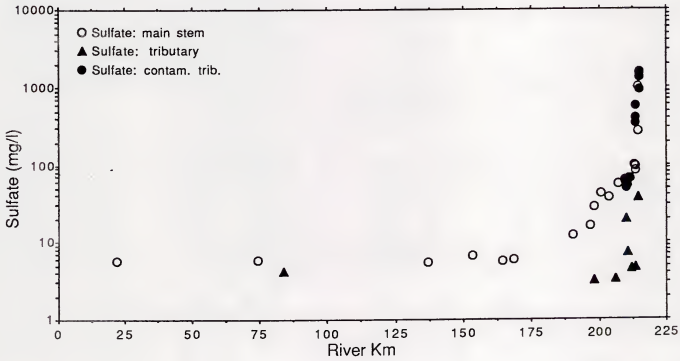
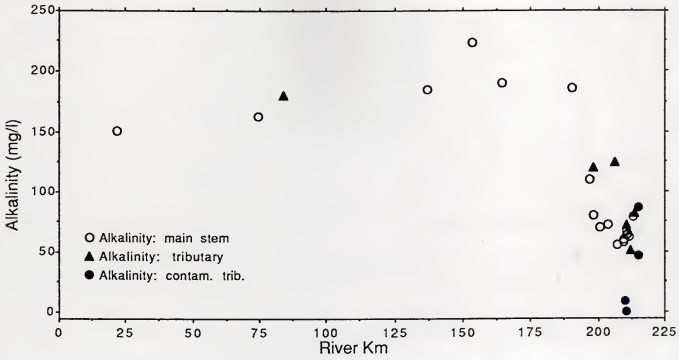


Figure 2C



Trends of Al, Cd, Cu, and Pb in water show minimal injection of contaminants downstream from the sources (Figures 3A-D; As was below detection limit, 0.05 mg/L, for all samples except in two mine effluents (Appendix 2), as was Ni (As, Ni and other elements analyzed are not plotted). Concentrations of these elements decrease to values equivalent to uncontaminated tributaries (mostly below detection limit) within the upper few Km of river. Iron, Mn and Zn show more intrusion downstream (Figure 3E-G), but nearly all solute components reach background values (uncontaminated tributary values) 25 km downstream. Only Zn shows irregularities from this trend (possibly resulting from sample contamination).

These trends show that although most solute trace-metals (Al, Cd, Cu, Mn, Ni and Pb) are all elevated from one to three orders of magnitude above background levels in the contaminated tributaries and

Figure 3A

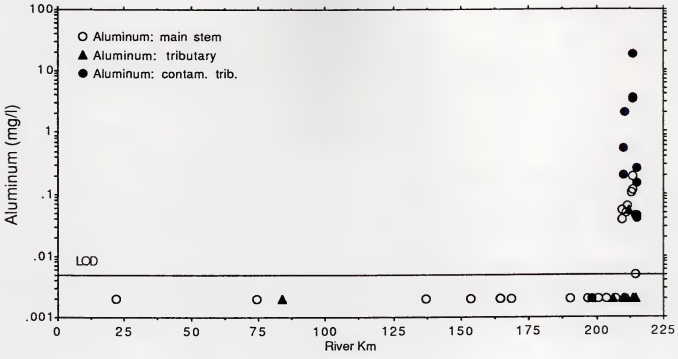


Figure 3B

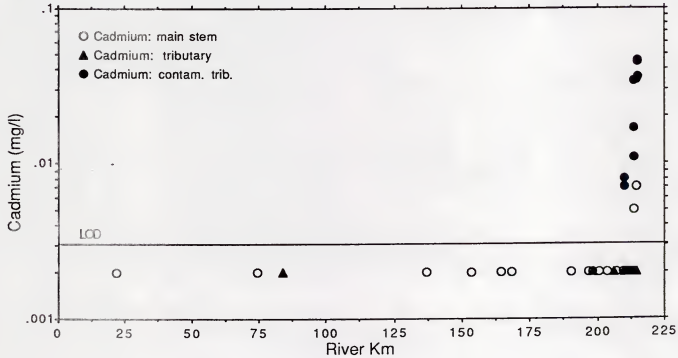


Figure 3C

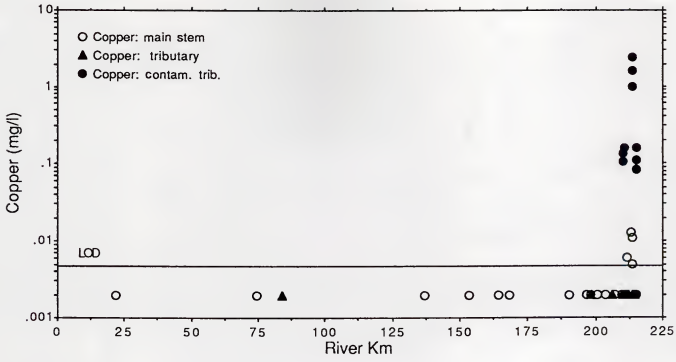


Figure 3D

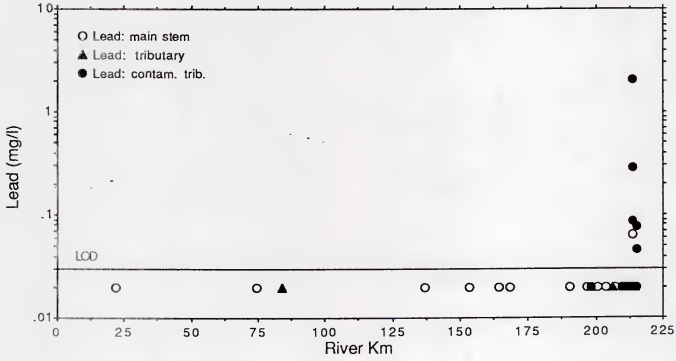


Figure 3E

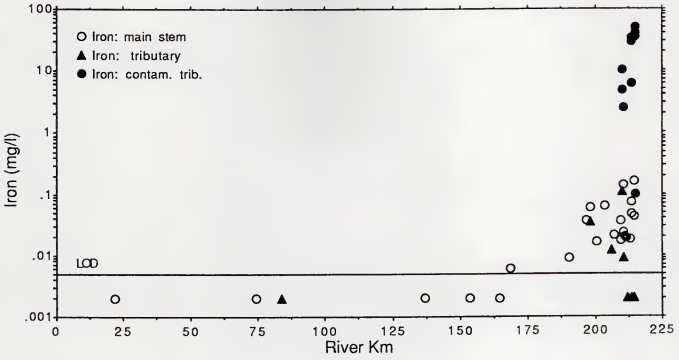


Figure 3F

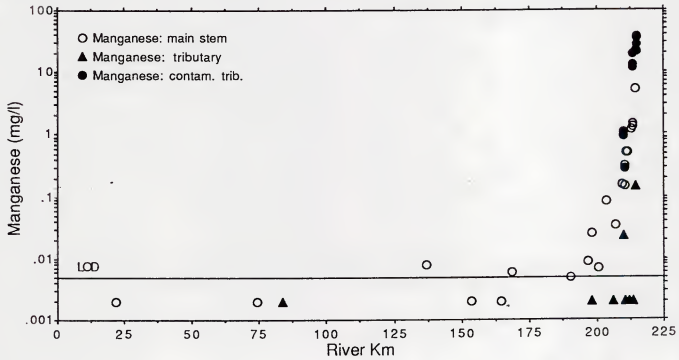
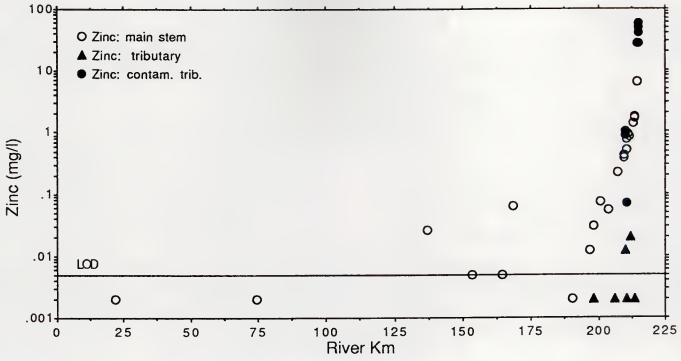


Figure 3G



the upper few Km of river, they decrease to background levels before entering the marsh systems at 211.5 to 204 km. However, sulfate, Fe, Mn and Zn penetrate farther downstream, into and through the upper marsh systems to approximately 190 km, 25 km downstream from the major source.

Total effluent input, from all adits and tunnels (all above 210 Km) during low flows, accounts for approximately 7 to 14% of total river flow at 207 Km (Spence 1975). These inputs are possibly diluted at high flows but no measurements have been made on mine inputs during spring runoff. Although there are several sources for the contaminants, one adit (Mike Horse Mine) supplies most of the flow into the headwaters. Approximately 80% of the mine effluent comes from the Mike Horse Mine at the farthest upstream (215.1 Km) input (Spence 1975).

Sediment Contaminants

Compositional characteristics are distinctly different and concentrations of the trace elements As, Cd, Cu, Mn, Ni, Pb and Zn are 10 to 1000 times higher in bed sediments in the upper few Km of the Blackfoot River than in uncontaminated tributaries (background values) or in sediment downstream (Figures 4A-G; Appendix 3). As is only high in the uppermost reaches of the river and Ni is less enriched

Figure 4A

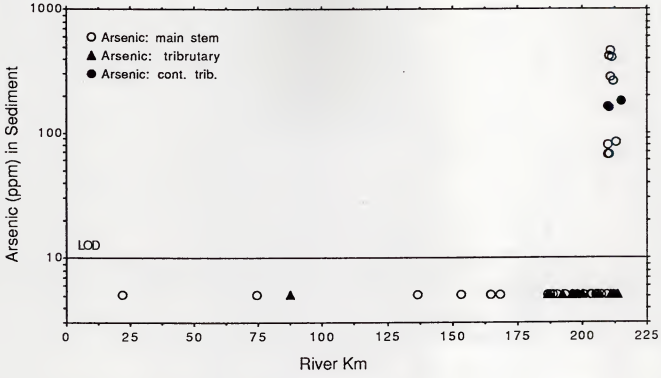


Figure 4B

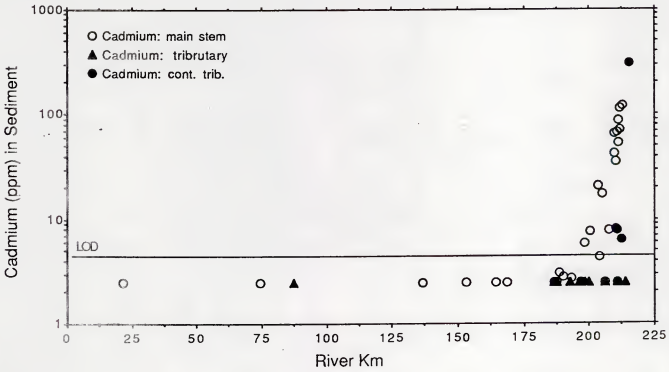


Figure 4C

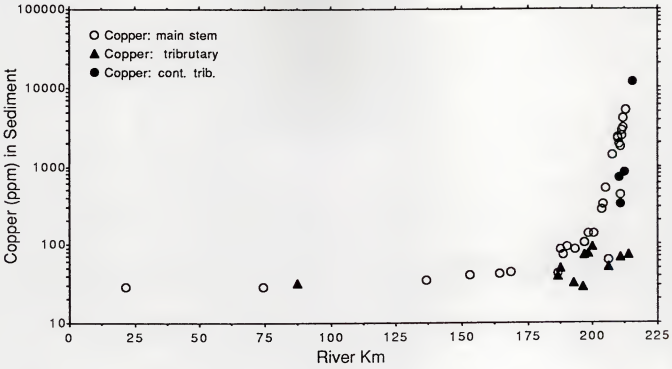


Figure 4D

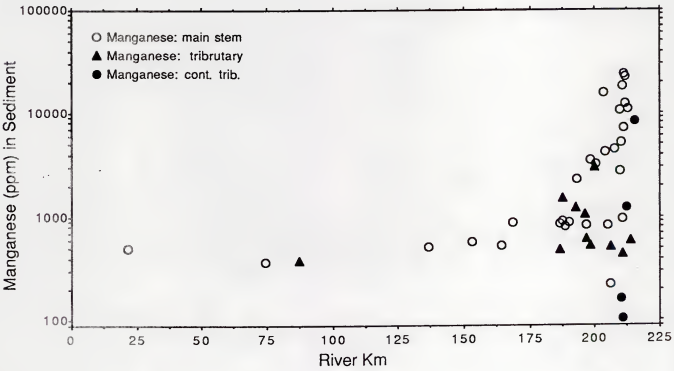


Figure 4E

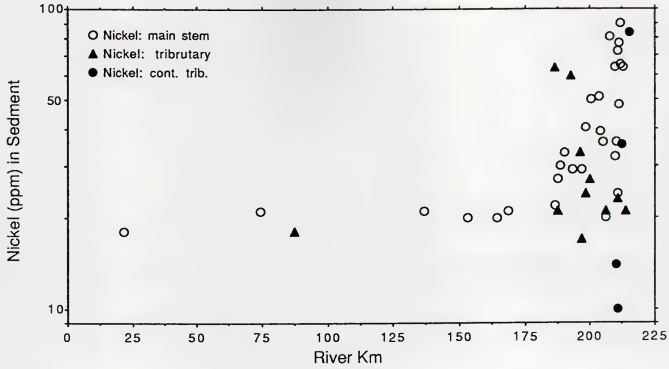


Figure 4F

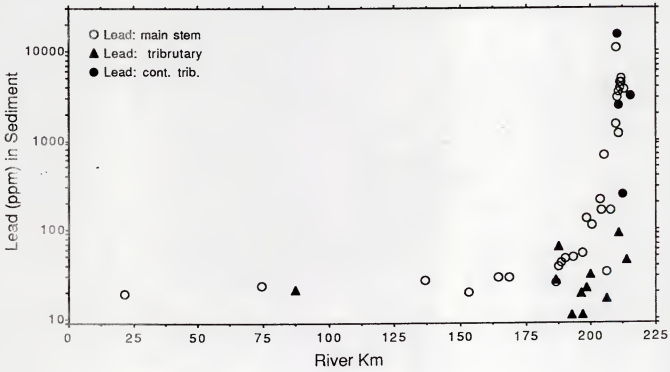
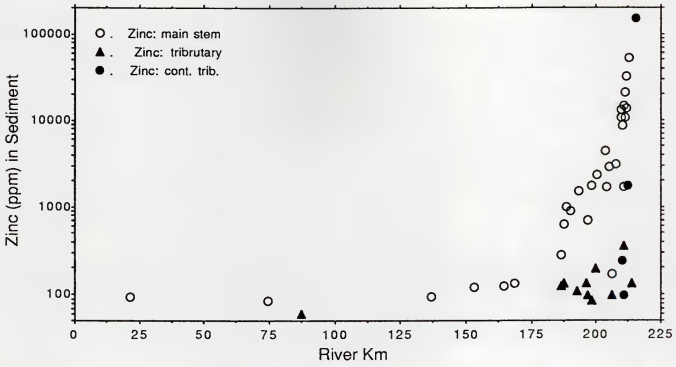


Figure 4G



than all other metals. Solute and sediment contamination have similar sources. The sediment contamination originates from a small number of headwater tributaries and the major input of Mike Horse Mine effluent at 215.1 Km in the headwater mainstem. Concentrations of metals in sediments decrease rapidly downstream, but no obvious step decrease is associated with marshes. Trace metal contamination in sediment is found downstream to approximately 190 Km, more than 10 Km beyond the marsh system.

Iron follows the trend of the trace elements (Figure 4H), higher-than-background concentrations penetrating downstream approximately 25 km from the main sources also to 190 Km. The elements Al, Ca and Ti show different trends (Figures 4I-K) with all three metals depleted in the headwaters, and one or two contaminated tributaries, and increasing rapidly to values similar to most tributary and downstream sediments.

In the upper few Km of river, it is visually apparent that contaminated sediment is associated with Fe-Mn oxyhydroxides. All contaminated tributaries and the upper main stem have beds coated with red-orange, oxyhydroxide precipitates. As acid mine drainage flows from the subsurface into the oxygenated surface waters, oxyhydroxides precipitate from solution, along with other hydroxide and sulfate minerals

Figure 4H

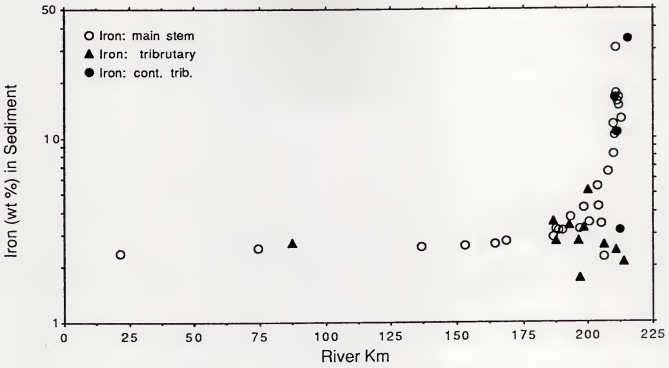


Figure 4I

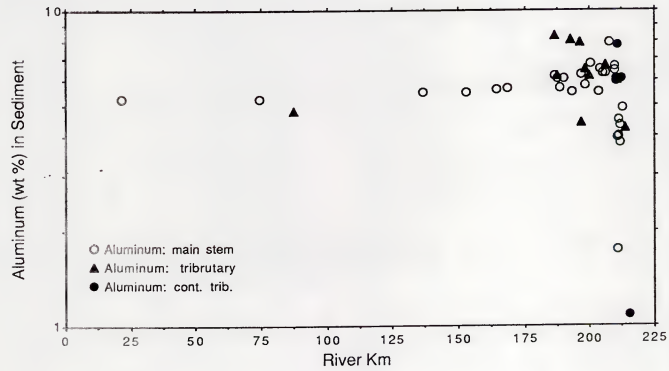


Figure 4J

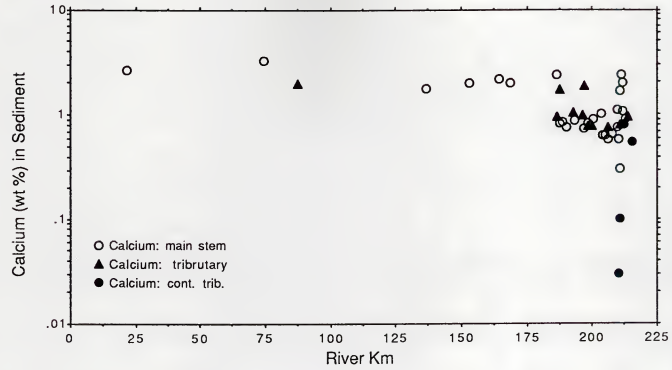
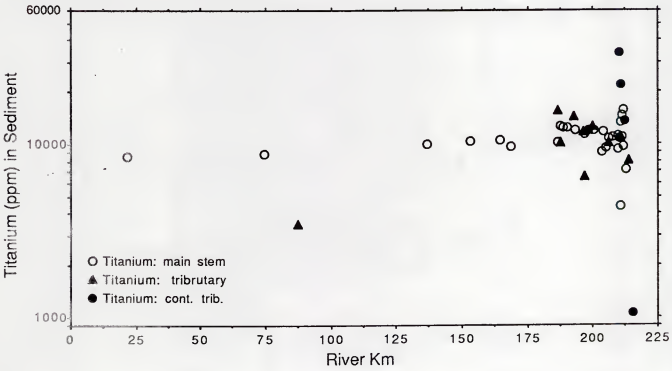


Figure 4K



(Nordstrom 1982). These oxyhydroxides act as a source for particulate contamination downstream (Jones 1986; Filipek et al. 1987; Nordstrom 1982).

Change in concentration of this particulate contamination through the marsh system delineate the ability of the marshes to mitigate contamination. Particulate contamination generally decreases through the entire marsh system, however, no clear step-like decrease is associated with the marshes and most of the decrease could be the result of downstream dilution of contaminants by uncontaminated sediment from tributaries.

Metals in Biota

A qualitative estimation of presence/absence of targeted benthic fauna and mayflies (a metal-sensitive order - Winner, et al, 1980) indicated important faunal groups were absent where sediment was most contaminated. No benthic biota were found at 211.8 Km where rocks were obviously coated with Fe-Mn oxyhydroxides. Limnophilids were the only targeted benthos found at 207 Km. The communities at 101 and 190Km also were missing taxa typical of such streams. For example, hydropsychid caddisflies and mayflies were absent at 200.5 Km in 1989. Absent groups at 190 Km included hydropsychid caddisflies in 1988 and 1989, perlid stoneflies in 1988 and mayflies at least in 1989 (the only year the search included mayflies). Hydropsychids, perlids and mayflies were present at 186.6 Km and all other downstream stations.

Downstream trends in metal concentrations in the food web of the river were similar in the three surveillances. Year-to-year variability at three stations are exemplified for Cd in three taxa in Table 2 (all data in Appendix 4). Because of the general agreement among years, data from 1987, 1988 and 1989 were aggregated to summarize spatial distributions in the following analysis.

Metals differed from one another in their bioavailability within and below the marsh system. Cadmium was the element most consistently accumulated throughout the food web. It was significantly enriched ($p<0.01$) in caddisflies, stoneflies, and brook trout collected from within the marsh system, when compared to downstream segments of the river (Table 3 and 4). Although only two cutthroat trout were found in the marsh collections, their livers contained concentrations of Cd more than 30 times higher than found at the reference site. Significant Cd enrichment also appeared throughout the food web at 190 Km,

Table 2

Year-to-year differences of cadmium concentrations at three stations in the Blackfoot River in two types of insect larvae and cutthroat trout. Caddisfly is *Arctopsyche grandis*. Data for *Hesperla pacifica* and *Claassenia sabulosa* are combined to obtain stonefly comparison. (NC = not collected; NP = not present).

Km	Year	Caddisfly	Stonefly	Cutthroat Trout
21.8	1987	<0.2	0.12	
	1988	0.30	0.10	
	1989	0.16	0.08	
74.4	1987	0.20	0.20	
	1987	0.18	0.09	
190	1987	NC	1.30	NC
	1988	3.27	NP	0.61 ± 0.21
	1989	1.26	0.76	0.60 ± 0.08

downstream from the marsh system, suggesting that the Cd contamination in sediments that penetrated through the marshes was bioavailable. Cadmium concentrations in caddisflies, stoneflies, and both species of trout were significantly higher at 190 Km than in the middle (137 to 168 Km) and lower (17 to 87 Km) segments of the river (Table 3 and 4). Cutthroat trout contained 3.3 times more Cd at 190 Km than in the reference area ($p<0.01$).

Bioavailable cadmium contamination appeared to extend to the middle reaches of the river. Cadmium concentrations in caddisflies were not significantly different between the middle and lower segments of the river (Table 3), as observed in sediments. However, in stoneflies and in large brown trout significant ($p<0.05$ for insects; $p<0.01$ for brown trout) Cd contamination was observed in the middle reach compared to the lower reach (Table 3 and 5). The longer life and/or predaceous nature of these two groups appeared to make them sensitive indicators of Cd contamination.

Table 3

Spatial distribution of cadmium *μg/g dry weight) in insect larvae in the Blackfoot River.
(NC = not collected; NP = not present).

Km	*Limnophilus*	*Brachycentrus*	*Arctopsyche*	*Hesperoperla*	*Claassenia*
211.8	NP	NP	NP	NP	NP
beginning of marshes					
207.3	1.8	NP	NP	NP	NP
200.5	NP	13.8	NP	0.64 ± 0.16	0.69 ± 0.30
end of marshes					
190	0.56 ± 0.14	2.3 ± 1.4	2.6 ± 0.08	1.04 ± 0.62	0.52 ± 0.17
186.6	0.42	0.54 ± 0.07	0.42	1.00	
168-137	NP	0.37 ± 0.21	0.07	0.27 ± 0.12	0.24 ± 0.04
74 - 87	NP	0.32 ± 0.11	0.14	0.14 ± 0.14	0.13 ± 0.06
Reference	NP	NC	0.10 ± 0.01		

Table 4

Cadmium, copper and zinc concentrations (μg/g dry weight ± one standard deviation) in the livers of trout from the Blackfoot River and a reference (Marshal Creek). All animals were 67 to 225 cm in length. The number of animals analyzed in one to six composites is shown in parentheses.

	Cadmium		Copper		Zinc	
Km	Brook	Cutthroat	Brook	Cutthroat	Brook	Cutthroat
211.8	18 ± 13 (6)	NP	1113 ± 351 (6)	NP	654 ± 68 (6)	NP
beginning of marshes						
207.3	9.4 ± 2.4 (25)	8.8 (2)	311 ± 51 (25)	24 (2)	324 ± 58 (25)	135 (2)
200.5	4.7 ± 1.5 (9)	5.9 (3)	182 ± 89 (9)	34 ± 18 (3)	235 ± 115 (9)	146 (3)
end of marshes						
190	0.70 ± 0.26 (7)	0.60 ± 0.08 (17)	135 ± 57 (7)	14 ± 5 (17)	138 ± 12 (7)	107 ± 3 (18)
186.6	<0.05 (1)	0.17 ± 0.06 (16)	54 (1)	13 ± 5 (16)	151 (1)	106 ± 1 (16)
Reference	NP	0.18±0.07 (18)	NP	15 ± 6 (18)	NP	103 ± 3 (18)

Table 5

Comparison of metal concentrations in livers of large brown trout (*Salmo trutta*), 341-475 cm in length), sampled in the middle reach of the Blackfoot River (near 123 and 134 Km) with trout sampled below the confluence of the North Fork of the Blackfoot River at 74 Km. (* = values significantly different from one another).

Km	n	Cadmium	Copper	Zinc
123-134	12	0.83 ± 0.42*	846 ± 398	111 ± 10
74	6	0.07 ± 0.05*	494 ± 223	111 ±

Table 6

Spatial distribution of copper (µg/g dry weight) in insect larvae in the Blackfoot River. Reference values are from Rock Creek, a tributary of the Clark Fork River unaffected by mine effluent.

Km	*Limnophilus*	*Brachycentrus*	*Arctopsyche*	*Hesperoerla*	*Claassenia*
211.8	NP	NP	NP	NP	NP
beginning of marshes					
207.3	27	NP	NP	NP	NP
200.5	NP	28.9	NP	32 ± 1	33 ± 6
end of marshes					
190	15 ± 2	17 ± 4	18 ± 1	23 ± 6	41 ± 5
186.6	27	16 ± 1	10	28	
168-137	NP	19 ± 3	15 ± 1	24 ± 3	42 ± 10
74-87	NP	16 ± 1	14 ± 4	29 ± 3	43 ± 8
Reference	NP	NC	12 ± 4	21	

Significant ($p<0.01$) Zn contamination of the food web also extended downstream through the middle reach of the river as evidenced in *Brachycentrus*, *Arctopsyche*, and *Hesperoperla* (Appendix 4). Concentrations of Zn in brook trout livers were enriched significantly within, but not below, the marsh system (Table 4). No significant differences in Zn concentrations occurred among stations in *Limnophilus* or *Claassenia*. The latter species may regulate Zn concentrations within their tissues.

Concentrations of Cu in the livers of brook trout collected above the marsh system were nearly 10 fold higher than in animals at 190 Km ($p<0.01$) (Table 4). However, brook trout was the only taxon in which substantial Cu contamination was observed, in contrast to the trends in sediment (Table 6). The Cu

concentration in the one brachycentrid composite from within the marsh was significantly ($p<0.05$), but only slightly, higher than observed at 190 Km. Otherwise no significant differences occurred among any segments of the river below the marshes ($p>0.05$), in insect larvae, cutthroat trout or brown trout (Table 4 and 6). Such results suggest Cu was either of less widespread availability in the Blackfoot River than were Cd or Zn, or Cu was physiologically regulated by most of the species studied. Arsenic and Ni were somewhat variable, but neither element showed consistent enrichment in any species in any segment of the river. Both appeared to be of low bioavailability (Appendix 4).

Historic Comparisons of Fish Populations

Trout populations were recently studied in the Blackfoot River (Peters and Spoon 1989) because of an increase in complaints about dwindling numbers of fish. Selected data from that study, relevant to the determinations of metal distributions, are presented here, and compared to surveys from the 1970's. The most striking results are from upstream. Eastern brook trout populations declined between 1971-73 and 1988 at three of four stations between 170 and 200 Km ; cutthroat trout populations declined at two of three relevant stations in this reach. Data from 200 Km illustrate the magnitude of those changes and the differences in response between species and age classes (Figures 5).

The surveys of Spence (1975) were conducted first in 1973, then again in 1975 following the failure of an abandoned tailings pond in the uppermost headwaters of the river (input at 214.6 Km just below the largest source of mine effluent). "Young-of-the-year" brook trout (age 0) were present in 1973 at 200 Km, but absent in 1975, suggesting acute mortalities from mine/milling wastes injected into the river by the pond failure (Figure 5). In 1988, age 0 brook trout populations had returned, but the fish were only 33% as abundant as in 1973. Age 1 (1 year old) and older brook trout showed no apparent mortality from the pond failure; population densities were the same in 1973 and 1975. However, the effects of poor recruitment that would be expected from the reduced abundance of age 0 fish were evident in 1988. Age 1 and older brook trout populations were 72% lower in 1988 than in 1973-75, declining in average density from 82/Km to 23/Km .

Age 0 cutthroat trout at 200 Km also showed severe acute mortality in 1975; age 1 and older cutthroat were reduced in abundance from 57% (compare 1973 and 1975 in Figure 5). Age 0 cutthroat populations in

1988 remained severely reduced compared to 1973, suggesting a limited recovery from mortality resulting from mining/milling waste inputs. In 1988, the abundance of age 1 and older cutthroat trout was less than 25% of that in 1973, and had declined by an additional 50% from 1975 (an 85% decline in cutthroat compared to 1975 was observed upstream at 207 Km in 1988).

Additional anomolies in trout populations were observed in the reaches of the river where the transition between species occurs. For example, at 170 Km significantly fewer age 1 brown trout and a possible downward trend in two year old plus older brown trout were observed from 1973 to 1988 (Figure 5), but no decline in age 0 brown trout was evident.

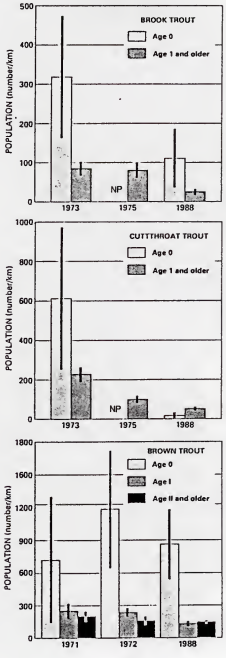
Discussion

In the Blackfoot River, some solute and particulate contaminants extend downstream for 25 Km from the major contaminant source while others contaminate only a few Km of river immediately below inputs. Concentration of solute contaminants decreases rapidly in the upper few Km of input, probably related to the precipitation of Fe-oxyhydroxides. As metal-rich mine effluent cascades down steep reaches of river, the entrainment of oxygen precipitates solute Fe and Mn (Michaelis 1988). The high concentration of sulfate also leads to the precipitation of metal sulfates (Nordstrom 1982). Other metals and metalloids can co-precipitate/adsorb with/onto these sulfates and oxyhydroxides. This system of solute contaminant precipitation/adsorption works well in decreasing solute metal contaminants in the Blackfoot drainage above the marsh system, but transfers metals to the particulate phase. Some solute and particulate contamination passes through the marsh system and, at least Cd and Zn remains bioavailable over long stretches of the river.

Of the targeted species in this study, only brook trout (a depauperate population) were found upstream of the marsh system. The livers of these animals suggested substantial bioavailability of Cd, Zn, and Cu, in conjuction with the high concentrations in sediments and water. Particulate metal concentration and values in brook trout correlate strongly throughout the river, with $r^2 = 0.971$ and 0.922 for Cu and Zn concentrations in sediment, and 0.938 for log Cd concentration in sediment. Zinc in brook trout is also correlated with Zn in water, $r^2 = 0.984$.

Figure 5

Plots of populatons of age 0 and age 1 + older brook trout at 200 Km, compared between the 1970's and 1988 (data from Peters and Spoon 1988).



Within the marsh and downstream, Cd contamination is more severe than Zn and affected more species. Arsenic and Ni originating from acid mine drainage are of low bioavailability consistent with their relatively low concentrations in both the solute and particulate phases. Elevated solute Cu concentrations decrease to near limits of detection before entering the marsh system , which may partially explain their limited availability to the biota. Although Cu is elevated in brook trout, the particulate Cu contamination that extends through the marsh system has no detectible effects on concentrations in other representatives from the food web.

Longer-lived, predaceous species appeared to be more sensitive indicators of downstream Cd contamination than either sediments, water or detritus feeding species. Significant Cd contamination was observed in stoneflies and large brown trout more than 75 Km downstream from the input of acid mine drainage. Zinc was also significantly enriched in some species in the middle reaches of the river. Thus, the order of downstream mobilization of bioavailable metals originating from the acid mine drainage appears to be Cd, Zn > Cu > As, Ni.

It is well established that natural marshes can improve water quality (Wolverton 1987) and that aquatic plants and bacteria can remove metals from acid mine drainage (McDonald 1981; Wolverton 1975; Wolverton and McDonald 1977). Natural and artificial marshes can decrease acidity, sulfate and metal solute concentrations in acid mine drainage by 1 to 2 orders of magnitude (Huntsman *et al.* 1978; Wieder *et al.* 1982) by precipitation, adsorption, hydrolysis, redox and photochemcial reactions, chelation and filtration. The period of time over which marshes provide effective mitigation and the pathways that transfer contaminants from the mine effluent to the biota are poorly known. The Blackfoot River is typical of Rocky Mountain rivers contaminated by abandoned mine drainage with a well established beaver pond/marsh system that has received mine effluent for more than 100 years. The Blackfoot example suggests that marsh systems may slow the transport of metals but they do not necessarily completely retard downstream contamination of the food web by the most mobile of the metals. Particulate contaminants generally penetrated the marsh system to a greater extent than did solute contamination, but the marsh system is complex geochemically, possibly acting as both sink and source for different particulate metal contaminants.

Other studies have shown that metals such as Cd, Pb and Zn adversely affect both trout and their food web (Duncan and Klaverkamp 1982; Niederlehner *et al.* 1984; Hendrix *et al.* 1985; Selby et al. 1985;

Harrison and Klaverkamp 1989; Schmiitt and Finger 1987; Schmitt *et al.* 1984), although manifestation of such effects can be complex (Mankittrick and Dixon 1988: Schindler 1986). Substantial contamination of sediment, water, and food webs from acid mine drainage, accompanied by depauperate benthic communities and fish populations in the Blackfoot River illustrates the effects of such metals when mobilized by acid mine drainage. Surveys of the Blackfoot River conducted during low flow in 1968 - 1971 (Spence, 1975) also indicated a reduced number of bottom fauna species, especially mayflies, at 206.6 Km and 198.1 Km but not at 192.6 Km or 186.5 Km . The present study detected sediment contamination at 190 Km and an absence of typical insect larvae (e.g. mayflies). This is a minimum data set, but it suggests that metal influences may extend further downstream than observed 16 years earlier.

Before natural or artificial marshes are considered as long-term solutions for remediation of continuous trace metal inputs from acid mine drainage on the Blackfoot River, this study suggests a thorough study of particulate, aqueous and biologic components and consideration of long-term changes is necessary. If the marsh system typically fails to mitigate upstream inputs of metals for an indefinite period, elimination of sources of metal input from all the contaminated tributaries may be the most effective mechanism for preventing extended, long-term riverine contamination in the Blackfoot River riparian systems. As well, the present marsh system must be managed to maximize its effectiveness at mitigating contaminant transport. Retention time of water and sediment must be maximized to limit intrusion of solute and particulate contaminants downstream from the headwater inputs. The entire upper Blackfoot must be managed as a system, integrating knowledge of the geochemistry, morphology and biology, to recover from past abuse in the drainage and preserve this important riparian resource for the future.

Recommendations

1. **Curtailment of solute inputs**. The several sources of contaminants in the headwaters must be stopped, or drastically reduced, before the Blackfoot River system can recover. The main input from the Mike Horse Mine must be abated as well as flows from Paymaster Gulch, Swamp Gulch, the Anaconda Mine, and other smaller inputs. What ever methods are used, it is important to slow or stop the input of metal-rich water to the system.

2. **Curtailment of particulate sources**. The many years of mine effluent inputs to the river has left a large non-point source of contaminants in the bed sediment of the river. Much of this remains above the marshes, although some has penetrated downstream. This downstream transport likely results from channeling of the river through the marsh systems (probably during the flooding associated with the tailings pond failure). It is likely that residence time of water in the marshes is low because of this configuration. Even if the solute inputs are stopped, to limit continued downstream movement of contaminants will require modifying the marshes to retain water (and therefore solute and particulate contaminants) over longer periods. For the uppermost marsh (which receives flow from all the contaminated tributaries and the main stem), re-establishment of beaver dams may aid retention of contaminants. For the second marsh, the channel needs to be re-channeled into the main system (it now passes south of the marsh). The highly contaminated sediments in the Blackfoot River above the marshes should be abated by establishment of a series of small artificial marshes. These should "stair step" upstream from approximately Shave Creek to Anaconda Creek. This would limit the downstream movement of particulate contaminants from this major upstream, non-point source.

Any mitigation of contamination should be done in conjunction with rebuilding the affected fisheries habitat. An integrated, system-wide approach should greatly reduce the transfer of metals into the food web of the Blackfoot River and hopefully lead to recovery of the Blackfoot fishery. Without this major effort, the large store of non-point source contaminants will continue to move into the food web of this complex riparian system.

Acknowledgements

This work could not have been accomplished without the continuing contribution of ideas and enthusiasm from Sam Luoma, Don Peters, D. Cain and E. Axtmann plus the able field assistance of E. Axtmann, D. Cain, M. Cook, S. Andrews, V. Elrod and D. Pridmore. Carolyn Johns originally suggested the idea of an integrated sediment-water-biota study on the Blackfoot and supplied laboratory and editorial assistance. Much of the writing of this report was done in conjunction with Sam Luoma and Don Peters for a joint-authored journal article submitted to the Canadian Journal of Fisheries and Aquatic Sciences.

References

Axtmann, E. V., D. J. Cain, and S. N. Luoma. 1990. Distributions of trace metals in fine-grained, bed sediments and benthic insects in the Clark Fork River, Montana: Proceedings, Clark Fork River Symposium, Missoula, MT April 20, 1989.

Bollingberg, H. J. 1979. Lead in spotted wolfish, *Anarcias minor*, near a zinc-lead mine in Greenland. J. Fish. Res. Board Can. 36:1023-1028.

Bradley, S. B. and J. J. Cox. 1987. Heavy metals in the Hamps and Manifold Valleys, Norht Staffordshire, U.K.: Partitioning of metals in floodplain soils. Sci. Total Envir. 65:135-153.

Brooks, R.R., J. R. Lewis, and R. D. Reeves. 1976. Mercury and other heavy metals in trout of Central North Island, New Zealand. Jour. Marine and Freshwater Res. 10:233-244.

Cain, D. J., J. L. Carter, and S. V. Fend. 1989. Temporal and spatial variability of arsenic in benthic insects from Whitewood Creek, South Dakota. *In* G. E. Mallard and S. E. Ragone (eds) U. S. Geological Survey Toxics Substances Hydrology Program-Proceedings of the technical meeting, Phoenix, AZ, Sept. 26-30, 1988: U. S. Geological Survey Water Resources Investigations Report 88-4220.

Chernoff, B. and J. K. Dooley. 1979. Heavy metals in relation to the biology of the mummichog, *Fundulus heteroclitus*. J. Fish. Biol. 14:309-328.

Dollhopf, D. J., J. D. Goering, R. B. Rennick, R. B. Morton, W. K. Gauger, J. B. Guckert, P. M. Jones, K. C. Cooksey, K. E. Bucklin, R. Weed, and M. M. Lehman. 1988. Hydrochemical, vegetational and microbiological effects of a natural and a constructed wetland on the control of acid mine drainage. Montana Department of State Lands, Abandoned Mine Reclamation Bureau, Helena, MT, Reclamation Research Publication 88-04, June 1988. 214 p.

Duncan, D. A., and J. F. Klaverkamp. 1982. Tolerance and resistance to cadmium in White Suckers (*Catostomus commersoni*) previously exposed to cadmium, mercury, zinc or selinium. Can J. Fish. Aquat. Sci. 40:128-138.

Filipek, L. H., D. K. Nordstron and W. H. Ficklin. 1987. Interaction of acid mine drainage with waters and sediments of west Squaw Creek in the West Shasta Mining district, California. Environ. Sci. Tech. 21:388-396.

Giesey, J. P., J. W. Bolling, H. J. Kania, R. L. Knight, and S. Mashburn. 1981. Fates of cadmium introduced into channels microcosm. Environment International. 5:159-175.

Harrison, S. E., and J. F. Klaverkamp. 1989. Uptake, elimination and tissue distribution of dietary and aqueous cadmium by rainbow trout (*Salmo gairdneri* Richardson) and Lake Whitefish (*Coregonus clupeaformis* Mitchill). Envir. Toxicol. Chem. 8:87-97.

Hendrix, P. E., C. L. Langner, and E. P. Odum. 1982. Cadmium in aquatic microcosms: Implications for screening the ecological effects of toxic substances. Environ. Management. 6:643-553.

Huntsman, B. E., J. G. Solch, and M. D. Porter. 1978. Utilization of *Spagnum* species dominated bog for coal acid mine drainage abatement. Geol. Soc. Amer. , 91st Ann. Symp., Toronto, Ontario.

Jones, K. C. 1986. The distribution and partitioning of silver and other heavy metals in sediments associated with an acid mine drainage stream. Environ. Pollution (B). 12:249-263.

Luoma, S. N., E. V. Axtmann, and E. J. Cain. 1989. Fate of mine wastes, Clark Fork RIver, Montana, U.S.A. *In* Metals and metalloids in the hydrosphere; impact through mining and industry. Asian Inst. Tech. (UNESCO), Bangkok, Thailand. p. 63-75.

MacFarlane and Franzin 1980 *** Sam

McDonald, R. C. 1981. Vascular plants for decontaminating radioactive water and soils. NASA Tech. Memorandum TM-X-72740.

Michaelis, H. V. 1988. Integrated biological systems for effluent treatment from mine and mill tailings. *In* W. Solomons and U. Forstner (*Eds*) Environmental Management of Solid Waste. Springer Verlag, NY. p. 99-112.

Moraiarity, F., K. R. Bull, H. M. Hanson and P. Freestone. 1982. The distribution of lead, zinc and cadmium in sediments of an ore-enriched lotic ecosystem, the River Ecclesbourne, Derbyshire. Environ. Pollution (B) 4:45-68.

Nehring, R. B. 1986. An evluation of the possible impacts of heavy metal pollution on the brown trout population of the upper Arkansas River. Colorado Div. Wildlife Report. 171p.

Niederlehner, B. R., A. L. Buikema, Jr., C. A. Pittinger, and J. Cairns, Jr. 1984. Effects of cadmium on the population growth of a benthic invertebrate *Aeolosoma headleyi* (Oligochaeta). Environ. Toxicol. Chem. 3:255-262.

Nordstrom, D. K. 1982. Aqueous pyrite oxidation and the consequent formation of secondary iron minerals. Soil Sci. Soc. Amer. Spec. Publ. 10:37-56.

NOVA. 1990. Poison in the Rockies (transcript of video). WGBH-TV, Boston, MA. p. 2-3.

Peters, D. and R. Spoon. 1988. Preliminary fisheries inventory of the Big Blackfoot Riber. Montana Department of Fish, Wildlife and Parks. 46p.

Ricker, W.F. 1975. Handbook of computations for biological statistics of fish populations. Fisheries Research Board Canada. 119, 300p.

Roch, M., J. A. McCarter, A. T. Matheson, M. R. Clark, and R. W. Olafson. 1982. Hepatic metallotionein in Rainbow trout (*Salmo gairdneri*) as an indicator of metal pollution in the Campbell River system. Can. J. Fish. Aquat. Sci. 39:1596-1601.

Schindler, D. W. 1986. Detecting ecosystem responses to anthropogenic stress. Can. J. Fish. Aquat. Sci. 44(Suppl. 1):6-25.

Schmitt, C. J., F. J. Dwyer, and S. E. Finger. 1984. Bioavailability of Pb and Zn from miune tailings as indicated by erythrocyte delta-aminolevulinic acid dehydratase (ALA-D) activity in suckers [Mo., U.S.A.}. Can. J. Fish Aquat. Sci. 44:1010-1040.

Schmitt, C. J., and S. E. Finger. 1987. Effects of sample preparation on measured concentrations of eight elements in edible tissues of fish from streams contaminated by Pb mining. Arch. Environ. Contam. Toxicol. 16:185-207.

Selby, D. A., J. M. Ihnat, and J. J. Messer. 1985. Effects of subacute cadmium exposure on a hard water mountain stream microcosm. Water Res. 19:646-655.

Spence, L. E. 1975. Upper Blackfoot River-A preliminary inventory of aquatic and wildlife resources. Montana Department of Fish and Game. 236p.

Weiner, J. G., and J. P. Giesy, Jr. 1979. Concentrations of Cd, Cu, Mn, Pb, and Zn in fisheries in a highly organic softwater pond. J. Fish. Res. Board Can. 36:270-279.

Wieder, R. K., G. E. Lang, and A. E. Whitehouse. 1982. Modification of acid mine drainage in a fresh water wetland. *In*, Proceedings, Acid Mine Drainage Research and Development, #rd West Virginia Surface Mine Drainage Task Force Symposium, Charleston, WV. p. 38-62.

Wolverton, B. C. 1975. Water hyacinths for removal of cadmium and nickel from polluted waters. NASA Technical Memorandum TM-X-72721.

Wolverton, B. C. and R. C. McDonald. 1977. Wastewater treatment utilizing water hyacinths (*Eichhornia crassipes*) (Mart) Solms. *In* Treatment and disposal of industrial wastewaters and residues. Proceedings of National Conference, Houston, TX. p. 205-208.

Wolverton, B. C. 1987. Artificial marshes for wastewater treatment. *In* Reddy, K. R., and W. H. Smith (*Eds*) Aquatic plants for water treatment and resource recovery. Magnolia Publ. Inc., Orlando, FL. p. 141-152.

Appendix 1

Sample Site Locations

Sample number includes a preface for either the Blackfoot River mainstem (BF) or a tributary (T), followed by the river Km measured from the mouth upstream (0 at the confluence with the Clark Fork River) for the mainstem sample or the river Km where the tributary enters the mainstem.

Sample Number	Site Location
BF 21.8	Johnsrud Park, along south bank, upstream from camping area near river.
BF 74.4	Scotty Brown Bridge, along south bank, downstream from bridge.
T 84.0	North Fork of the Blackfoot River, Harry Morgan Fishing access, along both banks downstream from campground.
BF136.9	Upstream from Avon Road Bridge, along highway on north side of river, at pullout area.
BF153.3	Upstream from Nevada-Ogden Road Bridge, along both banks mostly upstream from Blackfoot Canyon Campground.
BF164.5	Along highway just downstream from Blackfoot Mine, at pullout area along steep road cut, above steep bank covered with large blocks of rock.
BF168.5	Dalton Mountain Road Bridge, upstream from bridge, on south side of river.
T186.5	Seven-Up Pete Creek, above confluence with Blackfoot River approximately 200 m.
BF186.6	Behind Seven-Up Supper Club at end of dirt road on north bank of river, samples from upstream and downstream of this road on both sides of river.
T187.3	Lander's Fork of the Blackfoot River, north of highway 200 bridge, on east both banks.
BF187.7	Upstream from mouth of Lander's Fork about 500 m, both banks of river.
BF188.4	At end of small dirt road leading southwest from entrance road to Aspen Grove Campground, along both sides of river.
BF190.0	Aspen Grove Campground, along both sides of river upstream from easternmost camp sites.
T192.4	Hogum Creek, approximately 10 m upstream from bridge on Hogum Road, about 0.8 Km upstream from confluence with Blackfoot River.
BF193.2	Upstream about 20 m from Hogum Road bridge crossing Blackfoot River, both sides of river.
T196.0	Horsefly Creek, access off Horse Creek Road at first small, heavily treed side canyon (west of road), site just downstream from where canyon widens.
BF196.6	Above Horsefly Creek-Flesher Lakes Road crossing, upstream about 30 m, along both banks.
T196.6	Hardscrabble Creek, Up Hardscrabble Creek along Alice Creek Road at first small pullout where creek runs next to the road.
BF 198.1	Upstream from confluence with Alice creek about 20-30 m, along both sides of creek.
T 198.1	Alice Creek, upstream about 30 m from Highway 200 bridge crossing Alice Creek, along both sides of creek.
T199.8	Willow Creek, About 100 m up creek from confluence with the Blackfoot River, approach through tunnel and downstream from Highway 279 crossing (not possible at high water!).

BF 200.5	Upstream from Highway 279 "bridge" crossing at small undeveloped campground at end of dirt road, along both sides of river.
BF 203.3	Along river just downstream from First Gulch, upstream about 10 m from a log bridge crossing the river, short dirt road from Highway 200 to river, both banks.
BF 203.7	On river at pullout along Highway 200 at First Gulch, in swampy channel. This site is not on the active channel of the Blackfoot River because it has shifted to the south. Therefore, data from this site not used.
BF 205.0	On river at pullout along Highway 200 at Second Gulch, in swampy channel. This site is not on the active channel of the Blackfoot River because it has shifted to the south. Therefore, data from this site not used.
BF 205.8	On river at pullout along Highway 200 at Third Gulch, in swampy channel. This site is not on the active channel of the Blackfoot River because it has shifted to the south. Therefore, data from this site not used.
T 206.1	Cadote Creek Road, along Cadote Creek Road where creel comes near road just below marsh area, about 40 m downstream from where road cuts into east slope of canyon.
BF 207.3	Below Pop's place (now gone) along river next to small dirt road that loops away from Highway 200 towards river, highly eroded banks in pasture area, both banks.
BF 209.5	Along River at Porcupine Gulch, just upstream about 10 m from bridge on Meadow Creek Road, both banks.
BF 209.8	In river directly north of Meadow Creek canyon, access across swampy area from Highway 200.
BF 210.0	Upstream from mouth of Meadow Creek canyon about 200 m, along south bank of river. Access from site BF 209.8 along channel.
T 210.0	Swamp Gulch, at small pond and outflow from Carbonate mine just north of Highway 200. Sediment samples from pond, water samples from outflow through weir.
BF 210.5	Upstream along channel from BF 210.0 about 500 m, just below an old beaver in the marsh area upstream.
BF 210.6	Channel in swamp just south of junction of Mike Horse Mine Road and Highway 200.
T 210.6	Paymaster Creek just below tailings and outflow from Paymaster Mine, above small culvert where creek runs beneath a dirt road.
T 210.8	Pass Creek, along dirt road south of creek about 700 m upstream from junction with Mike Horse Mine Road.
BF 211.0	In channel next to Mike Horse Mine Road, near confluence with Pass Creek.
BF 211.2	Upstream from BF 211.0 about 200 m, in channel just upstream of the junction between the road up Pass Creek and the Mike Horse Mine Road.
BF 211.6	Downstream from BF 211.8 about 200 m in channel, access from upstream.
BF 211.8	Above Paymaster Gulch road, a small dirt road crossing the river from the Mike Horse Mine Road.
T 212.1	Shave Creek, at culvert on Mike Horse Mine Road.
BF 212.9	Main channel along Mike Horse Mine Road about 800 m upstream from Shave Creek confluence.
BF 213.52	Just downstream of seep at site BF 213.52, below mixing zone of effluent and river.
T 213.55A	Small seep of acid mine water on east bank of river channel in line with Anaconda Mine.

BF 213.57	Just upstream from Anaconda Mine in line with drainage from mine, on east side of channel.
T 213.55B	At adit above main tailings piles of Anaconda Mine, from water filling adit and running down slope of tailings.
T213.55C	In very small, shallow pond formed at base of adit outflow below tailings pile at Anaconda Mine.
BF 214.6	In Beartrap Creek below mixing area of flow from the large tailings pond and Mike Horse Creek.
BF 214.65	Mike Horse Creek, upstream from inflow from tailings pond, very near confluence with Beartrap Creek.
T 215.0	Mike Horse Creek upstream from culvert beneath road to large tailings pond.
T 215.09	Below mixing of adit outflow from Mike Horse Mine and Mike Horse Creek, about 20 m downstream from adit.
T 215.1	Outflow from Mike Horse Mine adit, below small v-notched board across flow.
T 215.2	In Mike Horse Creek a few m above confluence of flow from the Mike Horse Mine adit.
T 215.5	In Mike Horse Creek, about 30 m above confluence with Mike Horse Mine adit.
T 216.0	At outflow from waste rock pile at head of Mike Horse Creek, on northern tributary above Mike Horse Mine, other tributary continues above main mining area.
T 217.0	Upstream at head of Mike Horse Creek above main workings, at end of road above workings.

Appendix 2

Water Chemistry Data from all sampling sites.

	A	B	C	D	E	F
1						
2						
3	Blackfoot Water Chemistry Data (mg/l)					
4	River Km	Sample Type	pH	Sulfate	Alkalinity	Aluminum
5	21.80	main stem	7.80	5.8	151	<0.02
6	74.40	main stem	7.70	6.0	163	<0.02
7	84.00	tributary	7.30	4.1	181	<0.02
8	136.90	main stem	7.80	5.5	185	<0.02
9	153.30	main stem	7.50	6.7	224	<0.02
10	164.50	main stem	7.40	5.8	190	<0.02
11	168.50	main stem	7.50	6.1	no meas.	<0.02
12	190.00	main stem	7.40	12	186	<0.02
13	196.60	main stem	7.65	17	110	<0.02
14	198.10	main stem	7.75	29	80	<0.02
15	198.10	tributary	8.05	3.2	120	<0.02
16	200.50	main stem	7.90	42	70	<0.02
17	203.70	main stem	7.60	38	72	<0.02
18	206.10	tributary	7.75	3.3	124	<0.02
19	207.30	main stem	7.50	56	56	<0.02
20	209.50	main stem	7.70	61	58	0.038
21	209.80	main stem	7.70	62	60	0.054
22	210.00	contam. trib.	6.10	61	9	0.196
23	210.00	contam. trib.	5.30	50	no meas.	0.544
24	210.00	tributary	6.60	20	no meas.	0.002
25	210.50	main stem	7.80	61	67	<0.02
26	210.60	contam. trib.	3.65	53	0	2.038
27	210.60	main stem	7.60	62	63	<0.02
28	210.80	tributary	7.70	7.2	72	<0.02
29	211.00	main stem	7.40	66	64	0.048
30	211.80	main stem	7.40	66	62	0.062
31	212.10	contam. trib.	7.85	4.6	51	0.054
32	212.90	main stem	7.30	97	79	0.103
33	213.52	main stem	7.40	82	no meas.	0.188
34	213.55	contam. trib.	3.40	575	no meas.	18.267
35	213.55	contam. trib.	4.00	331	no meas.	3.634
36	213.55	contam. trib.	3.20	396	no meas.	3.431
37	213.57	main stem	7.20	95	no meas.	0.116
38	213.70	tributary	8.05	4.7	82	<0.02
39	214.60	main stem	7.70	263	no meas.	0.044
40	214.62	tributary	7.50	37	no meas.	<0.02
41	214.65	main stem	7.30	974	no meas.	0.005
42	215.00	contam. trib.	7.10	914	47	0.039
43	215.09	contam. trib.	6.65	1295	no meas.	0.045
44	215.10	contam. trib.	6.60	1490	87	0.143
45	215.10	contam. trib.	6.20	1550	no meas.	0.256
46	215.20	contam. trib.	7.85	40	78	0.08
47	215.50	contam. trib.	7.70	39	no meas.	0.11
48	216.00	contam. trib.	7.40	10	no meas.	0.04
49	217.00	tributary	8.20	8	no meas.	0.10

	G	H	I	J	K	L
1						
2						
3	Blackfoot Water Chemistry Data (mg/l)					
4	Arsenic	Calcium	Cadmium	Copper	Iron	Magnesium
5	<0.03	31	<0.005	<0.005	<0.005	11
6	<0.03	32	<0.005	<0.005	<0.005	11
7	<0.03	31	<0.005	<0.005	<0.005	13
8	<0.03	41	<0.005	<0.005	<0.005	12
9	<0.03	43	<0.005	<0.005	<0.005	12
10	<0.03	43	<0.005	<0.005	<0.005	12
11	<0.03	42	<0.005	<0.005	0.006	12
12	<0.03	27	<0.005	<0.005	0.009	11
13	<0.03	28	<0.005	<0.005	0.037	13
14	<0.03	25	<0.005	<0.005	0.061	13
15	<0.03	29	<0.005	<0.005	0.034	13
16	<0.03	25	<0.005	<0.005	0.016	14
17	<0.03	25	<0.005	<0.005	0.062	13
18	<0.03	30	<0.005	<0.005	0.012	14
19	<0.03	25	<0.005	<0.005	0.021	14
20	<0.03	25	<0.005	<0.005	0.017	14
21	<0.03	26	<0.005	<0.005	0.036	15
22	<0.03	12	0.008	0.105	10.3	6
23	<0.03	12	0.007	0.133	4.692	6
24	<0.03	10	<0.005	0.002	0.111	5
25	<0.03	28	<0.005	<0.005	0.138	16
26	<0.03	5	<0.005	0.157	2.47	4
27	<0.03	27	<0.005	<0.005	0.023	16
28	<0.03	19	<0.005	<0.005	0.009	8
29	<0.03	28	<0.005	<0.005	0.020	16
30	<0.03	28	<0.005	0.006	0.019	16
31	<0.03	13	<0.005	<0.005	<0.005	6
32	<0.03	37	<0.005	0.013	0.018	23
33	<0.03	41	<0.005	0.005	0.074	22
34	<0.03	77	0.034	2.342	28.8	44
35	<0.03	86	0.017	1.584	33.1	27
36	<0.03	101	0.011	0.994	6.15	31
37	<0.03	38	0.005	0.011	0.047	22
38	<0.03	20	<0.005	<0.005	<0.005	10
39	<0.03	69	0.007	<0.005	0.041	50
40	0.033	32	<0.005	<0.005	<0.005	18
41	<0.03	182	0.035	<0.005	0.163	146
42	<0.03	201	0.046	<0.005	0.100	145
43	0.046	221	0.036	0.085	35.9	171
44	<0.03	309	0.045	0.156	40.6	213
45	0.058	310	0.046	0.109	49.0	207
46	<0.03	28	0.02	0.14	0.01	15
47	<0.03	30	0.02	0.17	0.01	15
48	<0.03	29	<0.005	0.013	0.019	14
49	<0.03	28	<0.005	0.006	0.047	14

	M	N	O	P
1				
2				
3	Blackfoot Water Chemistry Data (mg/l)			
4	Manganese	Nickel	Lead	Zinc
5	<0.005	<0.02	<0.04	<0.005
6	<0.005	<0.02	<0.04	<0.005
7	<0.005	<0.02	<0.04	<0.005
8	0.008	<0.02	<0.04	0.025
9	<0.005	<0.02	<0.04	0.005
10	<0.005	<0.02	<0.04	0.005
11	0.006	<0.02	<0.04	0.064
12	0.005	<0.02	<0.04	<0.005
13	0.009	<0.02	<0.04	0.012
14	0.026	<0.02	<0.04	0.030
15	<0.005	<0.02	<0.04	<0.005
16	0.007	<0.02	<0.04	0.072
17	0.083	<0.02	<0.04	0.054
18	<0.005	<0.02	<0.04	<0.005
19	0.035	<0.02	<0.04	0.217
20	0.156	<0.02	<0.04	0.381
21	0.157	<0.02	<0.04	0.425
22	1.06	<0.02	<0.04	1.02
23	0.945	<0.02	<0.04	0.867
24	0.023	<0.02	<0.04	0.012
25	0.149	<0.02	<0.04	0.507
26	0.282	<0.02	<0.04	0.068
27	0.311	<0.02	<0.04	0.770
28	<0.005	<0.02	<0.04	<0.005
29	0.504	<0.02	<0.04	0.903
30	0.520	<0.02	<0.04	0.829
31	<0.005	<0.02	<0.04	0.020
32	1.16	<0.02	<0.04	1.36
33	1.28	<0.02	0.06	1.74
34	19.6	0.077	2.08	6.41
35	11.9	0.033	0.09	3.79
36	13.2	0.030	0.29	3.67
37	1.46	<0.02	<0.04	1.67
38	<0.005	<0.02	<0.04	<0.005
39	5.30	0.022	<0.04	6.49
40	0.149	<0.02	<0.04	0.037
41	21.0	0.090	<0.04	28.0
42	21.4	0.093	<0.04	26.7
43	27.8	0.117	<0.04	41.4
44	35.4	0.145	0.05	50.6
45	36.8	0.155	0.08	56.9
46	0.17	<0.02	<0.04	2.88
47	0.093	<0.02	<0.04	3.09
48	<0.005	<0.02	<0.04	0.38
49	0.019	<0.02	<0.04	0.02

Appendix 3

Sediment Chemistry Data from all sampling sites.

	A	B	C	D	E	F
1	Blackfoot Sediment Chemistry Data					
2						
3	River Km	Sample Type	Aluminum	Arsenic	Calcium	Cadmium
4			(wt %)	(ppm)	(wt %)	(ppm)
5						
6	21.80	main stem	5.22	<8	2.68	<2.5
7	74.40	main stem	5.25	<8	3.26	<2.5
8	136.60	main stem	5.52	<8	1.78	<2.5
9	153.30	main stem	5.52	<8	1.99	<2.5
10	164.50	main stem	5.61	<8	2.16	<2.5
11	168.50	main stem	5.67	<8	1.99	<2.5
12	186.60	main stem	6.21	<8	2.40	<2.5
13	187.70	main stem	6.09	<8	0.82	<2.5
14	188.40	main stem	5.68	<8	0.85	3.1
15	190.00	main stem	6.07	<8	0.75	2.8
16	193.20	main stem	5.49	<8	0.88	2.7
17	196.60	main stem	6.23	<8	0.74	<2.5
18	198.10	main stem	5.75	<8	0.83	5.8
19	200.50	main stem	6.78	<8	0.91	7.5
20	203.30	main stem	5.52	<8	1.00	21
21	203.70	main stem	6.47	<8	0.64	4.3
22	205.00	main stem	6.31	<8	0.63	17
23	205.80	main stem	6.28	<8	0.57	<2.5
24	207.30	main stem	7.88	<8	0.65	7.8
25	209.50	main stem	6.45	<8	0.76	41
26	209.80	main stem	6.60	79	1.11	66
27	210.00	main stem	5.97	67	0.58	35
28	210.50	main stem	1.75	66	0.30	7.9
29	210.60	main stem	3.95	410	1.68	66
30	211.00	main stem	4.49	277	2.38	53
31	211.20	main stem	4.00	456	2.34	88
32	211.60	main stem	3.79	400	1.98	71
33	211.80	main stem	4.30	257	1.08	115
34	212.90	main stem	4.88	84	0.91	119
35	215.00	cont. trib.	1.08	180	0.54	310
36	87.30	tribrutary	4.80	<8	1.98	<2.5
37	186.50	tribrutary	8.31	<8	0.95	<2.5
38	187.30	tribrutary	6.18	<8	1.70	<2.5
39	192.40	tribrutary	8.08	<8	1.04	<2.5
40	196.00	tribrutary	7.87	<8	0.99	<2.5
41	196.60	tribrutary	4.39	<8	1.86	<2.5
42	198.10	tribrutary	6.47	<8	0.77	<2.5
43	199.80	tribrutary	6.20	<8	0.77	<2.5
44	206.10	tribrutary	6.71	<8	0.75	<2.5
45	210.00	cont. trib.	6.08	160	0.03	8.0
46	210.60	cont. trib.	7.73	156	0.10	<2.5
47	210.80	tribrutary	6.00	<8	0.80	<2.5
48	212.10	cont. trib.	6.04	<8	0.79	6.3
49	213.70	tribrutary	4.24	<8	0.96	<2.5

	G	H	I	J	K	L
1	Blackfoot Sediment Chemistry Data					
2						
3	Copper	Iron	Manganese	Nickel	Lead	Titanium
4	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
5						
6	29	2.40	503	18	19	8574
7	29	2.60	373	21	24	8939
8	35	2.60	519	21	27	10069
9	41	2.60	592	20	20	10324
10	42	2.60	547	20	29	10521
11	45	2.80	896	21	29	9754
12	42	2.90	872	22	25	10266
13	86	3.20	917	27	38	12609
14	74	3.10	810	30	42	12480
15	92	3.20	904	33	48	12411
16	88	3.70	2298	29	49	11910
17	103	3.20	838	29	55	11331
18	140	4.20	3492	40	132	12004
19	137	3.50	3223	50	111	11995
20	275	5.40	15665	51	214	9099
21	322	4.20	4220	39	162	11857
22	524	3.40	839	36	684	9520
23	63	2.30	226	20	33	10716
24	1405	6.60	4428	81	161	10935
25	2287	11.7	10718	64	1475	9287
26	2224	8.20	2800	32	10540	11091
27	1888	10.2	5258	36	2969	10749
28	428	30.4	967	24	1156	4425
29	1797	17.4	18358	72	3378	13268
30	2385	10.6	7178	48	3837	14655
31	2811	15.6	23812	77	4406	11012
32	3033	14.8	12359	65	4890	15697
33	4051	16.3	22460	89	4301	9660
34	5081	12.6	10862	64	3699	7199
35	11570	34.1	8296	83	3095	1064
36	33	2.70	394	18	21	3530
37	39	3.50	497	64	27	15804
38	50	2.80	1535	21	64	10269
39	32	3.40	1261	60	11	14268
40	29	2.80	1074	33	19	11761
41	75	1.70	623	17	11	6509
42	78	3.30	545	24	22	12034
43	92	5.20	3036	27	31	12660
44	52	2.60	519	21	17	10261
45	706	16.4	163	14	15029	33625
46	330	10.7	103	10	2414	22094
47	69	2.50	456	23	92	10974
48	850	3.20	1257	35	246	13617
49	75	2.10	615	21	46	8059

	M
1	Blackfoot S
2	
3	Zinc
4	(ppm)
5	
6	93
7	84
8	93
9	119
10	123
11	134
12	277
13	628
14	1022
15	918
16	1520
17	706
18	1771
19	2314
20	4398
21	1703
22	2881
23	171
24	3100
25	10555
26	13296
27	8581
28	1677
29	14446
30	10846
31	21159
32	13470
33	31793
34	51950
35	149448
36	60
37	125
38	132
39	109
40	136
41	98
42	86
43	201
44	98
45	245
46	99
47	360
48	1763
49	133

Appenidx 4

Data from Biologic Sampling from all sites.

	A	B	C	D	E
1	Blackfoot Fish Liver Chemical Data (ppm, dry weight)				
2					
3	River Km	Fish Type	Length (mm)	Aluminum	Arsenic
4					
5	211.80	Brook Trout	212.00	12.76	2.09
6	211.80	Brook Trout	198.00	14.16	1.15
7					
8	207.30	Brook Trout	268.00	54.12	0.83
9	207.30	Brook Trout	173.00	9.45	BD
10	207.30	Brook Trout	127.00	7.60	BD
11	207.30	Brook Trout	101.00	12.31	BD
12	207.30	Brook Trout	67.00	14.39	BD
13	207.30	Cutthroat Trout	159.00	6.32	BD
14					
15	200.50	Brook Trout	190.00	5.04	0.60
16	200.50	Brook Trout	170.00	4.48	2.40
17	200.50	Brook Trout	141.00	5.83	BD
18	200.50	Brook Trout	110.00	19.71	BD
19	200.50	Cutthroat Trout	295.00	4.92	2.00
20	200.50	Cutthroat Trout	291.00	2.42	2.00
21	200.50	Cutthroat Trout	153.00	4.60	2.64
22					
23	190.00	Brook Trout	228.00	1.64	1.59
24	190.00	Brook Trout	225.00	2.19	1.24
25	190.00	Brook Trout	213.00	1.02	0.88
26	190.00	Brook Trout	185.00	1.00	1.43
27	190.00	Cutthroat Trout	189.00	2.95	1.18
28	190.00	Cutthroat Trout	157.00	3.60	1.54
29	190.00	Cutthroat Trout	142.00	2.40	1.92
30	190.00	Cutthroat Trout	126.00	2.13	2.17
31					
32	186.60	Brook Trout	155.00	12.04	BD
33	186.60	Cutthroat Trout	265.00	2.36	1.65
34	186.60	Cutthroat Trout	198.00	2.15	1.90
35	186.60	Cutthroat Trout	123.00	2.20	1.95
36	186.60	Cutthroat Trout	98.00	2.81	BD
37	186.60	Brown Trout	245.00	1.32	1.99

	F	G	H	I	J	K
1						
2						
3	Cadmium	Copper	Iron	Manganese	Nickel	Lead
4						
5	8.40	865.00	679.00	9.20	BD	1.89
6	27.10	1362.00	886.00	10.40	BD	3.59
7						
8	47.50	228.00	2296.00	11.50	BD	1.52
9	11.50	329.00	829.00	6.40	BD	BD
10	12.30	365.00	569.00	8.70	BD	BD
11	6.20	323.00	487.00	10.40	0.93	BD
12	8.30	308.00	406.00	8.80	1.64	BD
13	8.80	24.00	565.00	10.20	BD	BD
14						
15	3.90	78.00	481.00	6.70	BD	BD
16	4.00	159.00	573.00	6.40	BD	BD
17	5.40	201.00	507.00	10.60	BD	BD
18	6.30	292.00	817.00	13.30	0.69	BD
19	6.20	20.00	553.00	6.60	BD	BD
20	7.70	27.00	880.00	11.00	BD	BD
21	5.90	54.00	573.00	8.20	BD	BD
22						
23	0.50	215.00	205.00	3.30	BD	BD
24	0.60	82.00	417.00	3.90	BD	BD
25	0.70	114.00	447.00	3.60	BD	BD
26	1.10	128.00	640.00	4.30	BD	BD
27	0.50	11.00	567.00	5.30	BD	BD
28	0.70	13.00	484.00	5.50	BD	BD
29	0.60	12.00	463.00	5.30	BD	BD
30	0.60	12.00	503.00	5.50	BD	BD
31						
32	BD	54.00	414.00	6.80	BD	BD
33	0.70	20.00	613.00	6.30	BD	BD
34	0.10	13.00	328.00	6.60	BD	BD
35	0.20	10.00	330.00	6.30	BD	BD
36	0.30	10.00	413.00	6.20	BD	BD
37	0.40	270.00	479.00	5.00	BD	BD

	L	M
1		
2		
3	Titanium	Zinc
4		
5	2.11	703.00
6	1.83	606.00
7		
8	1.10	282.00
9	3.49	284.00
10	3.44	324.00
11	5.07	306.00
12	5.88	424.00
13	3.38	135.00
14		
15	1.00	122.00
16	3.10	197.00
17	4.74	227.00
18	10.38	392.00
19	1.42	121.00
20	1.97	158.00
21	3.67	146.00
22		
23	1.09	143.00
24	1.34	121.00
25	0.28	139.00
26	1.46	148.00
27	1.76	104.00
28	1.93	111.00
29	1.06	104.00
30	2.75	108.00
31		
32	6.68	151.00
33	0.86	107.00
34	1.19	107.00
35	1.81	105.00
36	3.58	105.00
37	1.43	126.00

Fish Liver Chemical Data from 1988 survey.

--Comparisons of mean metal concentrations in livers of several fish species from Blackfoot Basin and Marshall Creek, a stream unaffected by mining. All valuea are in u/g dry weight ± 95% confidence interval. Comparisons are of similar sized individuals of the same species, but collected from different river segments. n = number of individuals analyzed. Where n =2, actual values are in parentheses.

Station	n	Range of lengths (cm)	Cd	Zn	Cu
Small Cutthroat					
Marshall Creek	18	69-117	0.18 ± 0.07	109 ± 3	15.0 ± 6
Blackfoot - 70 Km	2	298-316	0.13 ± 0.16(0.20, 0.05)	111 ± 22 (121, 100)	38.5 ± 32 (54, 23)
Blackfoot - 166 Km	11	85-200	0.61 ± 0.21	116 ± 10	22 ± 7
Large Brown Trout					
Blackfoot - 70 Km	6	341-450	0.07 ± 0.05	111 ± 9	494 ± 223
Blackfoot - 123 + 134 Km	12	345-475	0.83 ± 0.42	111 ± 10	846 ± 398
Small Brown Trout					
Blackfoot - 19 + 70 Km	3	142-205	(<0.1, <0.3, 0.06)	(121, 134, 128)	(312, 337, 249)
Blackfoot - 123 ± 134 Km	3	118-280	(0.14, 0.28, 0.28)	(141, 116, 99)	(167, 131, 397)
Small Long-nose Sucker					
Blackfoot - 19 Km	2	142-151	<0.10, <0.10	128 ± 40 (156, 99)	28 ± 13 (21, 34)
Blackfoot - 166 Km	5	72-122	0.77 ± 0.58	187 ± 76	20 ± 4
Large Long-nose Sucker					
Blackfoot - 19 Km	8	328-510	0.66 ± 0.49	140 ± 13	93 ± 16
Blackfoot - 70 Km	8	410-510	0.81 ± 0.47	147 ± 22	125 ± 65
Blackfoot - 123 Km	5	355-475	1.67 ± 1.75	113 ± 11	82 ± 37
Blackfoot - 134 Km	8	392-455	0.92 ± 0.48	124 ± 48	93 ± 55
Blackfoot - 123 + 134 Km	13	355-475	1.17 ± 0.62	117 ± 19	103 ± 21

Chemical Data from 1987, 1988 and 1989 for all benthic insect taxa collected.

Concentrations of cadmium (microgram per gram dry weight) in caddisfly larvae from Blackfoot River, Montana---1987, 1988, 1989 low flow periods. Stations identified by kilometers from mouth of river. ? means sample weight less than 200 milligrams. *Two additional samples omitted because >2000 microgram per gram aluminum in body indicates contaminated sediment in gut.

Station	Arctopsyche			Hydropsyche			Brachycentrus		Limnophilus
	1987	1988	1989	1987	1988	1989	1988	1989	1989
211.8									
207.3	1.84*								
200.5	13.8								
190	2.49	3.27				1.26	0.8,0.5,		2.61
	0.5,0.5								
	0.6								
186.6						0.42			
	0.59	0.42							
	0.49								
168.5		<0.2							0.09
		0.32							
167	<0.3							<0.6	
164.5		0.07							0.13
		0.19							
									0.05
153.3	0.23?					0.61			
136.9	0.33?								
84		bd							bd
	0.31								
	0.43?								

74.4	≤0.1 0.06?	0.18?	0.21	bd	
21.8	<0.2	0.14 0.18?		bd	0.07
North Fork R.		0.15		0.65	

Concentrations of copper (microgram per gram dry weight) in caddisfly larvae from Blackfoot River, Montana---1987, 1988, 1989 low flow periods. Stations identified by kilometers from mouth of river. ? means sample weight less than 200 milligrams. *Two additional samples omitted because >2000 microgram per gram aluminum in body indicates contaminated sediment in gut.

Station	Arctopsyche			Hydropsyche			Brachycentrus		Limnophilus
	1987	1988	1989	1987	1988	1989	1988	1989	1989
211.8									
207.3									26.8*
200.5								29.4	
190	17.7 17.9						19.6	14.2	20,14,14 14,14,15
186.6			10.4					16.7 14.8	27
168.5		15.3			19.0		17.7		
167	14.0			16					
164.5		15.9			19.4 18.5		16.8		
153.3					26.0		22.7		
136.9					22.3				
84		16.1			21.4		15.2 15.5		
74.4	12.0 22.0	11.1		24.0	23.5		16.5		
21.8	12.0 12.0	11.3 12.0		22.0	19.0				
North Fork R.		12.4		24.5					

Concentrations of cadmium (microgram per gram dry weight) in stonefly larvae from Blackfoot River, Montana---1987, 1988, 1989 low flow periods. Stations identified by kilometers from mouth of river.

Station	Hesperoperla			Claassenia			Pteronarcid	
	1987	1988	1989	1987	1988	1989	1987	1988
200.5			0.75 0.53			0.47 0.91		
190	0.72 1.91		0.49 1.02	0.63 0.61 0.32				
186.6			1.00					
168.5		0.32			0.23 0.22			
167	0.2 0.2 0.3			0.2 0.2			0.1	
164.5		0.04 0.26			0.26			0.03 0.08
153.3		0.34 0.29			0.22			
136.9		0.26 0.28 0.52			0.29 0.30			
84		0.24			0.06 0.12 0.22			0.04 0.03 0.03
74.4				0.1 0.2	0.05 0.13		0.1,0.1 0.1,0.2	0.05,0.17 0.14
21.8	<0.15	0.04		<0.15	0.07 0.15 0.15		0.09 0.11 0.03	0.09 0.13 0.16
North Fork R.		0.13			0.19			

Concentrations of nickel (microgram per gram dry weight) in caddisfly larvae from Blackfoot River, Montana---1987, 1988, 1989 low flow periods. Stations identified by kilometers from mouth of river. ? means sample weight less than 200 milligrams. *Two additional samples omitted because >2000 microgram per gram aluminum in body indicates contaminated sediment in gut.

Station	Arctopsyche			Hydropsyche			Brachycentrus		Limnophilus
	1987	1988	1989	1987	1988	1989	1988	1989	1989
211.8									
207.3									0.76
200.5								6.15	
190							0.59	bd	0.3,0.5, 0.4,0.3
186.6			0.28					0.79 3.55	1.62
168.5		1.80			1.36		0.94		
167									
164.5		1.24			1.62 0.93		0.76		
153.3					1.88		1.79		
136.9					3.61				
84		6.79			5.29		1.05 2.00		
74.4		1.65			1.55		1.04		
21.8		1.70 1.46			0.96				
North Fork R.		0.61			1.12				

Concentrations of zinc (microgram per gram dry weight) in caddisfly larvae from Blackfoot River, Montana---1987, 1988, 1989 low flow periods. Stations identified by kilometers from mouth of river. ? means sample weight less than 200 milligrams. *Two additional samples omitted because >2000 microgram per gram aluminum in body indicates contaminated sediment in gut.

Station	Arctopsyche			Hydropsyche			Brachycentrus		Limnophilus
	1987	1988	1989	1987	1988	1989	1988	1989	1989
211.8									
207.3									153*
200.5								1017	
190	355 366						417	521	114,172, 184,169, 193,349
186.6			140					548 530	476
168.5		171			123		373		
167	174			158					
164.5		159			115 98		348		
153.3					136		477		
136.9					138				
84		167			146		251 216		
74.4	119 129	140		240?	102		180		
21.8	141 132	128 122		111	99				
North Fork R.		139		353					

Concentrations of arsenic (microgram per gram dry weight) in caddisfly larvae from Blackfoot River, Montana---1987, 1988, 1989 low flow periods. Stations identified by kilometers from mouth of river. ? means sample weight less than 200 milligrams. Al indicates aluminum, an interfering element on ICP, exceeded 500 micrograms per gram in the sample.

Station	Arctopsyche			Hydropsyche			Brachycentrus		Limnophilus
	1987	1988	1989	1987	1988	1989	1988	1989	1989
211.8									
207.3									bd
200.5								Al	
190							1.7	2.9	1.8,1.7, 1.9,1.7, 1.9
186.6			1.8					3.5 4.0	Al
168.5		3.5			2.2		3.8		
167.3									
164.5		2.2			2.9 2.3		3.4		
153.3					Al		Al		
136.9					Al				
84		4.6			4.3		2.8 Al		
74.4		2.8			Al		Al		
21.8		Al			Al				
North Fork R.		3.95			4.79				

Concentrations of arsenic (microgram per gram dry weight) in stonefly larvae from Blackfoot River, Montana---1987, 1988, 1989 low flow periods. Stations identified by kilometers from mouth of river. *Small, young(?) animals; at 191 km not present the previous year. .

Station	Hesperoperla			Claassenia			Pteronarcid	
	1987	1988	1989	1987	1988	1989	1987	1988
211.8								
207.3								
200.5			bd bd			1.24 bd		
190			1.34 bd					
186.6			1.66					
168.5		0.63			1.36 0.55			
167								
164.5		1.66 1.84			1.11			8.60 3.70
153.3		0.38 1.48			1.70			
136.9		0.26 1.89 2.58			1.68 1.79			
84		1.53			0.79 1.08 1.29			5.42 4.37 6.59
74.4					0.95 0.91			4.3,5.0 4.7
21.8		bd			0.87 1.56 2.14			4.93 7.15 6.87
North Fork R.		4.36			1.32			

Concentrations of zinc (microgram per gram dry weight) in stonefly larvae from Blackfoot River, Montana---1987, 1988, 1989 low flow periods. Stations identified by kilometers from mouth of river. *Small, young(?) animals; at 191 km not present the previous year. .

Station	Hesperoperla			Claassenia			Pteronarcid	
	1987	1988	1989	1987	1988	1989	1987	1988
211.8								
207.3								
200.5			890			311		
			1001			354		
190	728		488*	215				
	633		480*	230				
				233				
186.6			570					
168.5		421			168			
					331			
167	440			236			174	
	527			225				
	417							
164.5		400			257			155
		454						175
153.3		461			244			
		406						
136.9		404			269			
		338			291			
		341						
84		340			170			135
					190			138
					170			144
74.4				159	143		165,170	126,129
				150	172		169,170	147
21.8	294	260		184	194		176	146
					194		207	171
					161		217	185
North Fork R.		354			407			

Concentrations of copper (microgram per gram dry weight) in stonefly larvae from Blackfoot River, Montana---1987, 1988, 1989 low flow periods. Stations identified by kilometers from mouth of river. *Small, young(?) animals; at 191 km not present the previous year. .

Station	Hesperoperla			Claassenia			Pteronarcid	
	1987	1988	1989	1987	1988	1989	1987	1988
211.8								
207.3								
200.5			31.3			37.1		
			32.8			28.9		
190	29.0		19.4*	41.3				
	28.7		16.5*	46.4				
				35.6				
186.6			27.8					
168.5		22.6			43.7			
					59.1			
167	25			41			37	
	28			36				
	26							
164.5		22.9			27.9			31.3
		22.0						27.5
153.3		17.8			45.8			
		19.4						
136.9		26.7			45.5			
		24.9			32.9			
		25.4						
84		28.7			49.0			25.1
					46.8			23.2
					39.2			26.7
74.4				39	50.2		37, 35	32.0,27.1
				33	44.6		34, 18	26.5
21.8	27	32		40	55.7		43	33.2
					45.8		38	34.3
					29.7		31	23.5
North Fork R.		21.0			65.5			

Concentrations of nickel (microgram per gram dry weight) in stonefly larvae from Blackfoot River, Montana---1987, 1988, 1989 low flow periods. Stations identified by kilometers from mouth of river. *Small, young(?) animals; at 191 km not present the previous year. .

Station	Hesperoperla			Claassenia			Pteronarcid	
	1987	1988	1989	1987	1988	1989	1987	1988
211.8								
207.3								
200.5			0.75			1.15		
			bd			2.47		
190			0.35					
			bd					
186.6			1.02					
168.5		0.95			1.24			
					0.75			
167								
164.5		0.66			3.59			2.93
		1.00						2.14
153.3		0.86			0.60			
		1.03						
136.9		0.59			0.65			
		1.50			0.49			
		1.23						
84		2.47			0.48			1.2
					0.38			0.9
					0.68			1.1
74.4					0.50			2.0,3.1
					0.68			2.3
21.8		0.68			0.53			2.24
					0.93			1.95
					0.30			0.75
North Fork R.		4.36			1.32			

Concentrations of arsenic (microgram per gram dry weight) in stonefly larvae from Blackfoot River, Montana---1987, 1988, 1989 low flow periods. Stations identified by kilometers from mouth of river. *Small, young(?) animals; at 191 km not present the previous year. .

Station	Hesperoperla			Claassenia			Pteronarcid	
	1987	1988	1989	1987	1988	1989	1987	1988
211.8								
207.3								
200.5			bd			1.24		
			bd			bd		
190			1.34					
			bd					
186.6			1.66					
168.5		0.63			1.36			
					0.55			
167								
164.5		1.66			1.11			8.60
		1.84						3.70
153.3		0.38			1.70			
		1.48						
136.9		0.26			1.68			
		1.89			1.79			
		2.58						
84		1.53			0.79			5.42
					1.08			4.37
					1.29			6.59
74.4					0.95			4.3,5.0
					0.91			4.7
21.8		bd			0.87			4.93
					1.56			7.15
					2.14			6.87
North Fork R.		4.36			1.32			